H2A: Hydrogen Analysis

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DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program

Systems Analysis Workshop

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Charter

- H2A mission: *Improve the transparency and consistency of approach to analysis, improve the understanding of the differences among analyses, and seek better validation from industry.*

- H2A was supported by the HFCIT Program

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History

- First H2A meeting February 2003
- Primary goal: bring consistency & transparency to hydrogen analysis
- Current effort is not designed to pick winners
  - R&D portfolio analysis
  - Tool for providing R&D direction

- Current stage: production & delivery analysis - consistent cost methodology & critical cost analyses
- Possible subsequent stages: transition analysis, end-point analysis

- Coordination with: Systems Integration, Program Tech Teams, efforts by H2A team member organizations

Skill Set - People

- H2A team:
  - Central: Johanna Ivy (NREL), Maggie Mann (NREL), Dan Mears (Technology Insights), Mike Rutkowski (Parsons Engineering)
  - Forecourt: Brian James (Directed Technologies, Inc.), Steve Lasher (TIAX), Matt Ringer (NREL)
  - Delivery: Marianne Mintz (ANL), Joan Ogden (UC Davis), Matt Ringer (NREL)
  - Finance, feedstocks, and methodology: Marylynn Placet (PNNL), Maggie Mann (NREL), Matt Ringer (NREL)
  - Environmental assessment: Michael Wang (ANL)
  - DOE: Mark Paster, Roxanne Danz, Pete Devlin
- Key Industrial Collaborators: AEP, Air Products, Areva, BOC, BP, ChevronTexaco, Conoco Phillips, Eastman Chemical, Entergy, Exxon Mobil, FERCO, GE, Praxair, Shell, Stuart Energy, Thermochem

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Skill Set – Capabilities Summary

TYPE OF ANALYSIS	RESIDENT CAPABILITY?	STUDIES SPECIFIC TO H_2?	MODELS SPECIFIC TO H_2?
Resource Analysis	No	No	No
Technoeconomic Analysis	Yes	Yes	Yes
Environmental Analysis	Yes	Yes	Yes
Delivery Analysis	Yes	Yes	Yes
Infrastructure Development Analysis	No	No	No
Energy Market Analysis	No	No	No

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Skill Set - Models

H2A Cash Flow Analysis Tool

- Developed over last year
- Documents assumptions, inputs, and results
- Modeling methodology: discounted cash flow rate of return analysis
  - Calculates levelized required selling price of hydrogen for a given IRR
  - Includes a set of agreed-upon financial assumptions but user can input their own set according to company preference
- Platform: Excel, with future links to GREET and Crystal Ball (Monte Carlo sensitivity analysis)
- Limitations:
  - Does not determine actual market price (that's okay for what it was designed to do)
  - Feedstock price projections based on EIA, but can be modified by user
  - Documentation not complete; no customer support line

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Skill Set - Models

H2A Cash Flow Analysis Tool

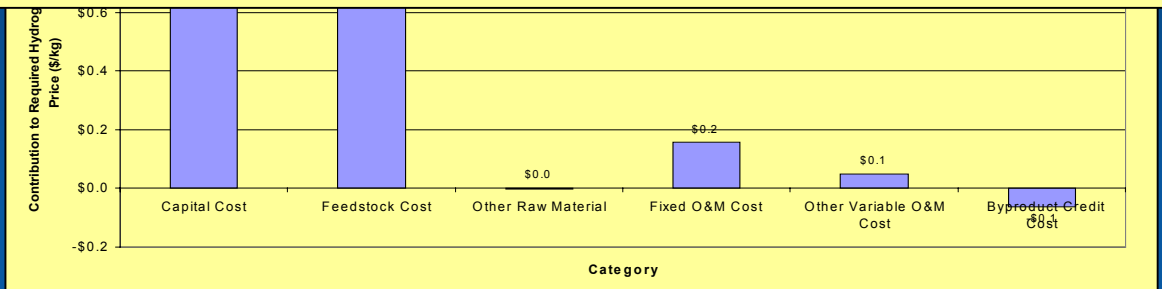
- Process Description
- Feedstock & Utility Prices
- Technology Performance Assumptions
- Process Flowsheet & Stream Summary
- Financing Inputs
- Cost Inputs
- Replacement Capital
- Cash Flow Analysis
- Results - Price of H2

VARIABLE PRODUCTION COSTS (at 100% capacity, startup year dollars)	
	Base Case:
Feedstock Costs	
Type of **electricity** used	none
Escalating **electricity** cost? (Enter yes or no)	Yes
Enter **electricity** cost if NO is selected above ($/kWh)	
Electricity consumption (kWh/kg H2)	
Electricity cost in startup year ($/kWh)	
Electricity cost ($/year, startup year dollars)	$0
Type of **natural gas** used	None
Natural gas energy content, LHV, if standard H2A value is not desired (GJ/Nm3)	0.038
Escalating **natural gas** cost? (Enter yes or no)	Yes
Enter **natural gas** cost if NO is selected above ($/Nm3)	
Natural gas consumption (Nm^3/kg of H2)	0

	Base Case	H2A Guidelines
decade increments)	2000	2000
umed Start-up Year	2005	2005, 2015, 2030
er-Tax Real IRR (%)	10%	10%
CRS, Straight Line)	MACRS	MACRS
ength (No. of Years)	20	20
lysis Period (years)	40	40
Plant Life (years)	40	40
ed Inflation Rate (%)	1.90%	1.90%
e Income Taxes (%)	6.0%	6%
l Income Taxes (%)	35.0%	35%
fective Tax Rate (%)	38.9%	
acity (kg of H2/day)	-	
Capacity Factor (%)	90%	Varies according to case
Output (kg H2/day)	-	
Plant Output (kg H2/year)	-	

Solve Cash Flow for Desired IRR

Hydrogen Selling Price and Cost Contributions (Year 2000 $)	
Required Hydrogen Selling Price ($(Year 2000)/kg of H2)	**$1.886**
Capital Cost Contribution ($/kg of H2)	$0.779
Feedstock cost contribution ($/kg of H2)	$0.642
Fixed O&M (labor etc.) cost contribution ($/kg of H2)	$0.217
Other Variable O&M cost contribution ($/kg of H2)	$0.248
Byproduct credit cost contribution ($/kg of H2)	$0.000



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Skill Set - Models

Key H2A Cash Flow Analysis Tool Assumptions

- + Reference year (2000 $)
- + Debt versus equity financing (100% equity)
- + After-tax internal rate of return (10% real)
- + Inflation rate (1.9%)
- Effective total tax rate (38.9%)
- Design capacity (varies)
- Capacity factor (90% for central (exc. wind); 70% for forecourt)
- Length of construction period (0.5 – 3 years for central; 0 for forecourt)
- Production ramp up schedule (varies according to case)
- Depreciation period and schedule (MACRS -- 20 yrs for central; 7 yrs for forecourt)
- Plant life and economic analysis period (40 yrs for central; 20 yrs for forecourt)
- Cost of land ($5,000/acre for central; land is rented in forecourt)
- Burdened labor cost ($50/hour central; $15/hour forecourt)
- G&A rate as % of labor (20%)

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Skill Set - Studies

- Completed base cases with sensitivity analysis for current, mid-term, and long-term technologies
  - Natural gas reforming: central and forecourt
  - Coal
  - Biomass
  - Nuclear
  - Central wind / electrolysis
  - Distributed electrolysis
  - Major delivery components and scenarios

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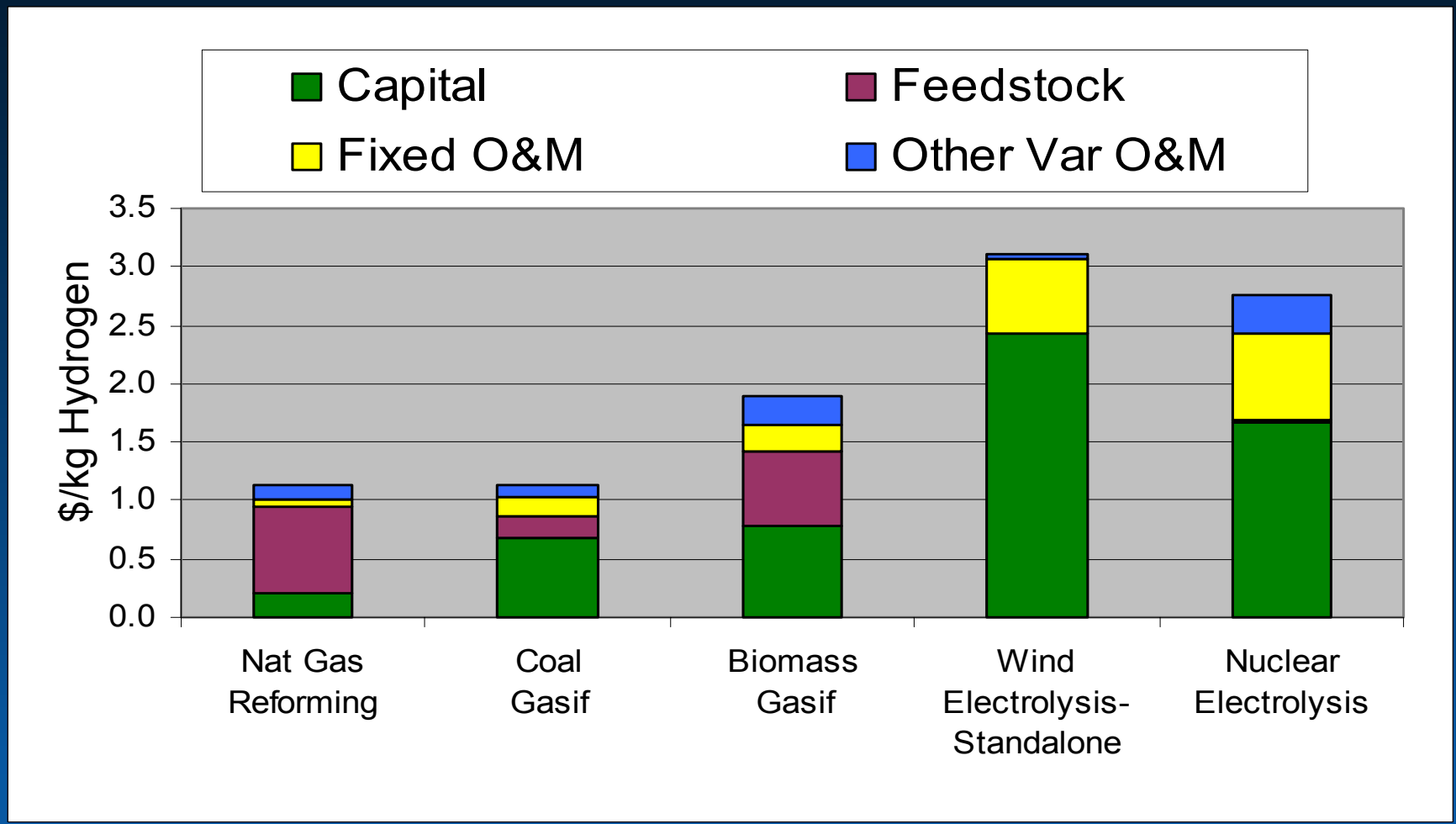
Example Results

Mid Term Central Technology Options
- $/kg Components -



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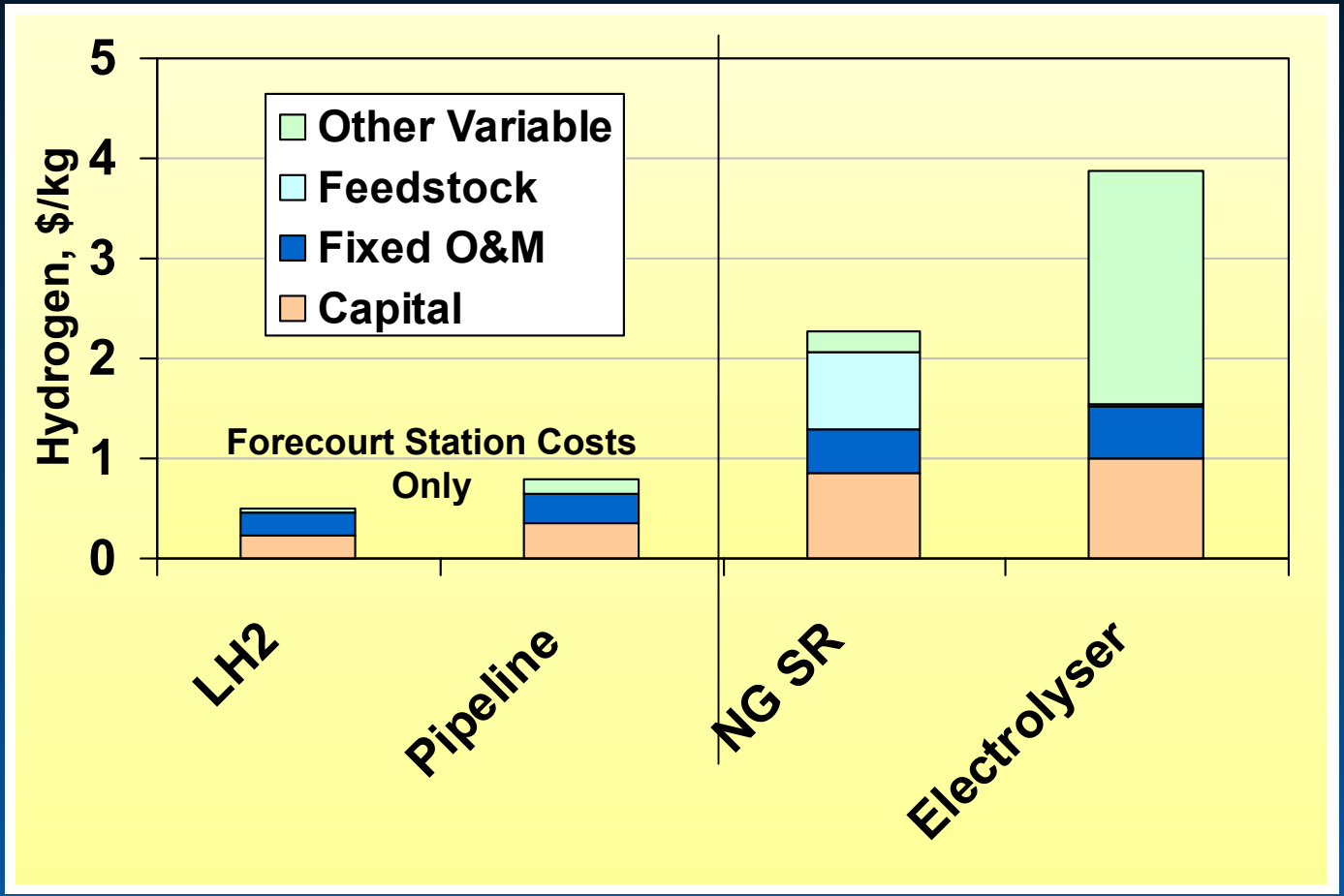
Example Results

Mid-term Forecourt Technology Summary



Note: For side by side comparison, central plant and delivery costs must be added to the Pipeline and LH_2 cases.

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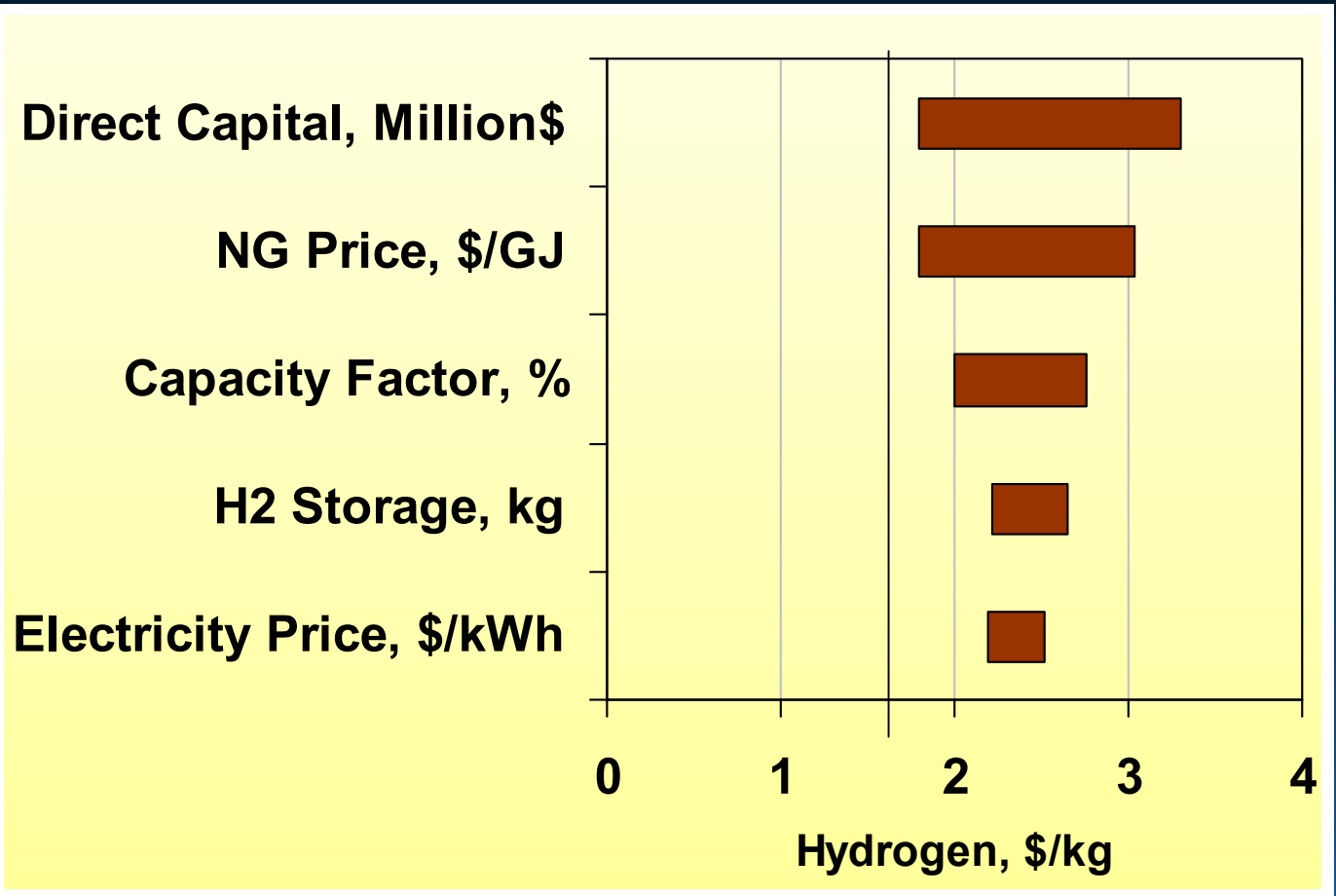
Example Results

Sensitivity Results: Mid-term Technology
- Large NG SR



Low	Base	High
0.9	1.8	3.1
1.85	~4.15	8.58
90	70	50
375	525	1,500
0.025	~0.048	0.12

Skill Set - Models

- Delivery Component Cost Model:
  - Allow user to access authoritative information on H_2 delivery component costs and performance
  - "Beta" test version will be released this summer
  - Platform: Excel
  - Limitations:
    - Not complete yet
    - Does not perform optimization calculations

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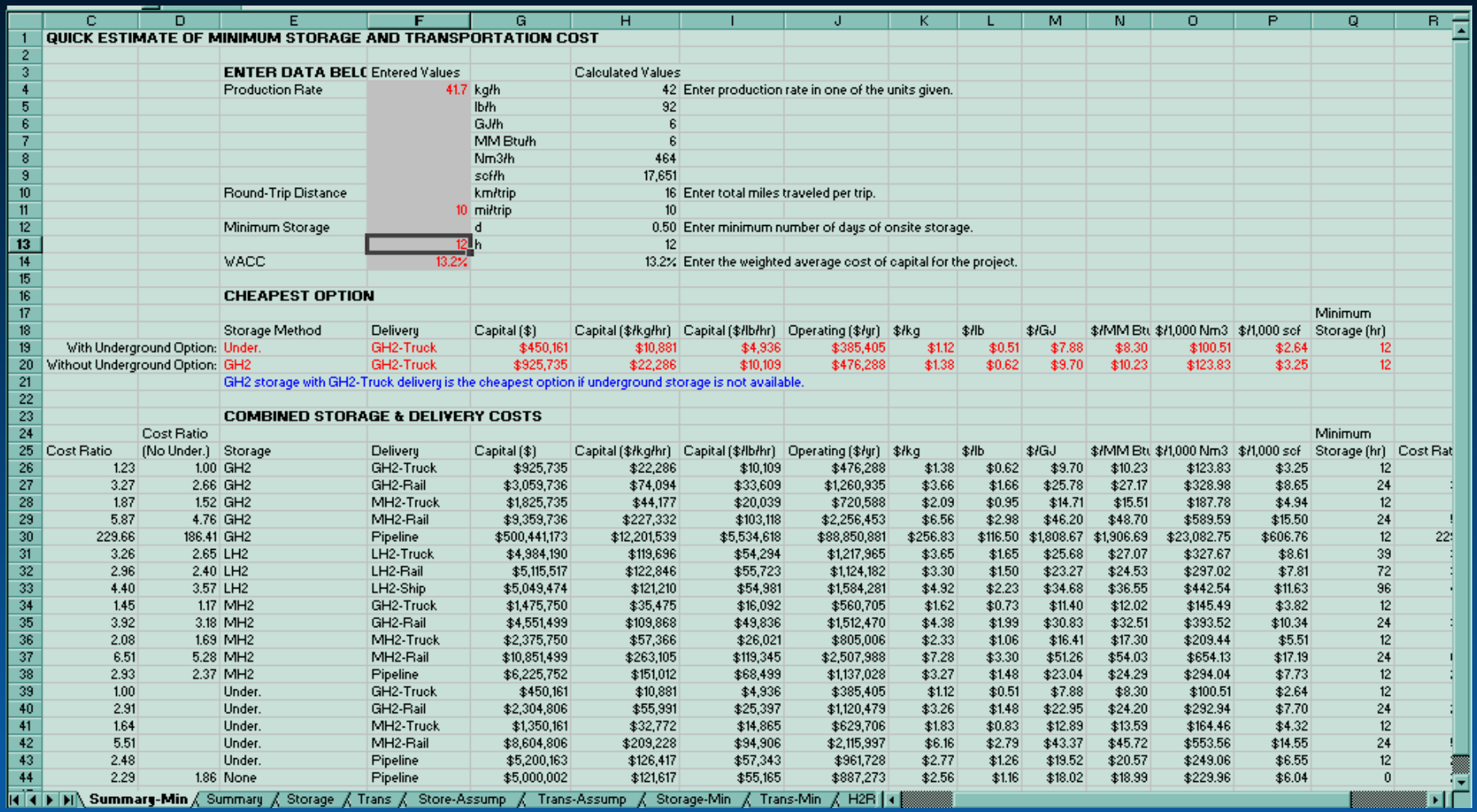
Skill Set - Models

Delivery Cost Component Model



	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	QUICK ESTIMATE OF MINIMUM STORAGE AND TRANSPORTATION COST															
2																
3			ENTER DATA BELO	Entered Values		Calculated Values										
4			Production Rate	41.7	kg/h	42	Enter production rate in one of the units given.									
5					lb/h	92										
6					GJ/h	6										
7					MM Btu/h	6										
8					Nm3/h	464										
9					scf/h	17,651										
10			Round-Trip Distance		km/trip	16	Enter total miles traveled per trip.									
11				10	mi/trip	10										
12			Minimum Storage		d	0.50	Enter minimum number of days of onsite storage.									
13				12	h	12										
14			WACC	13.2%		13.2%	Enter the weighted average cost of capital for the project.									
15																
16			CHEAPEST OPTION													
17															Minimum	
18			Storage Method	Delivery	Capital ($)	Capital ($/kg/hr)	Capital ($/lb/hr)	Operating ($/yr)	$/kg	$/lb	$/GJ	$/MM Btu	$/1,000 Nm3	$/1,000 scf	Storage (hr)	
19	With Underground Option:		Under.	GH2-Truck	$450,161	$10,881	$4,936	$385,405	$1.12	$0.51	$7.88	$8.30	$100.51	$2.64	12	
20	Without Underground Option:		GH2	GH2-Truck	$925,735	$22,286	$10,109	$476,288	$1.38	$0.62	$9.70	$10.23	$123.83	$3.25	12	
21			GH2 storage with GH2-Truck delivery is the cheapest option if underground storage is not available.													
22																
23			COMBINED STORAGE & DELIVERY COSTS													
24		Cost Ratio													Minimum	
25	Cost Ratio	(No Under.)	Storage	Delivery	Capital ($)	Capital ($/kg/hr)	Capital ($/lb/hr)	Operating ($/yr)	$/kg	$/lb	$/GJ	$/MM Btu	$/1,000 Nm3	$/1,000 scf	Storage (hr)	Cost Rat
26	1.23	1.00	GH2	GH2-Truck	$925,735	$22,286	$10,109	$476,288	$1.38	$0.62	$9.70	$10.23	$123.83	$3.25	12	
27	3.27	2.66	GH2	GH2-Rail	$3,059,736	$74,094	$33,609	$1,260,935	$3.66	$1.66	$25.78	$27.17	$328.98	$8.65	24	
28	1.87	1.52	GH2	MH2-Truck	$1,825,735	$44,177	$20,039	$720,588	$2.09	$0.95	$14.71	$15.51	$187.78	$4.94	12	
29	5.87	4.76	GH2	MH2-Rail	$9,359,736	$227,332	$103,118	$2,256,453	$6.56	$2.98	$46.20	$48.70	$589.59	$15.50	24	
30	229.66	186.41	GH2	Pipeline	$500,441,173	$12,201,539	$5,534,618	$88,850,881	$256.83	$116.50	$1,808.67	$1,906.69	$23,082.75	$606.76	12	22
31	3.26	2.65	LH2	LH2-Truck	$4,984,190	$119,696	$54,294	$1,217,965	$3.65	$1.65	$25.68	$27.07	$327.67	$8.61	39	
32	2.96	2.40	LH2	LH2-Rail	$5,115,517	$122,846	$55,723	$1,124,182	$3.30	$1.50	$23.27	$24.53	$297.02	$7.81	72	
33	4.40	3.57	LH2	LH2-Ship	$5,049,474	$121,210	$54,981	$1,584,281	$4.92	$2.23	$34.68	$36.55	$442.54	$11.63	96	
34	1.45	1.17	MH2	GH2-Truck	$1,475,750	$35,475	$16,092	$560,705	$1.62	$0.73	$11.40	$12.02	$145.49	$3.82	12	
35	3.92	3.18	MH2	GH2-Rail	$4,551,499	$109,868	$49,836	$1,512,470	$4.38	$1.99	$30.83	$32.51	$393.52	$10.34	24	
36	2.08	1.69	MH2	MH2-Truck	$2,375,750	$57,366	$26,021	$805,006	$2.33	$1.06	$16.41	$17.30	$209.44	$5.51	12	
37	6.51	5.28	MH2	MH2-Rail	$10,851,499	$263,105	$119,345	$2,507,988	$7.28	$3.30	$51.26	$54.03	$654.13	$17.19	24	
38	2.93	2.37	MH2	Pipeline	$6,225,752	$151,012	$68,499	$1,137,028	$3.27	$1.48	$23.04	$24.29	$294.04	$7.73	12	
39	1.00		Under.	GH2-Truck	$450,161	$10,881	$4,936	$385,405	$1.12	$0.51	$7.88	$8.30	$100.51	$2.64	12	
40	2.91		Under.	GH2-Rail	$2,304,806	$55,991	$25,397	$1,120,479	$3.26	$1.48	$22.95	$24.20	$292.94	$7.70	24	
41	1.64		Under.	MH2-Truck	$1,350,161	$32,772	$14,865	$629,706	$1.83	$0.83	$12.89	$13.59	$164.46	$4.32	12	
42	5.51		Under.	MH2-Rail	$8,604,806	$209,228	$94,906	$2,115,997	$6.16	$2.79	$43.37	$45.72	$553.56	$14.55	24	
43	2.48		Under.	Pipeline	$5,200,163	$126,417	$57,343	$961,728	$2.77	$1.26	$19.52	$20.57	$249.06	$6.55	12	
44	2.29	1.86	None	Pipeline	$5,000,002	$121,617	$55,165	$887,273	$2.56	$1.16	$18.02	$18.99	$229.96	$6.04	0	

Summary-Min | Summary | Storage | Trans | Store-Assump | Trans-Assump | Storage-Min | Trans-Min | H2R

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Skill Set - Studies

Delivery Scenarios

Market Type	Early Fleet Market (1%)	General Light Duty Vehicles: Market Penetration		
		Small (10%)	Medium (30%)	Large (70%)
Metro	X	X	X	X
Rural			X	
Interstate			X	

Delivery costs are based on component combinations that meet the demands of the market

3 Delivery Modes: Compressed Gas Truck; Liquid H2 Truck; Gas Pipeline

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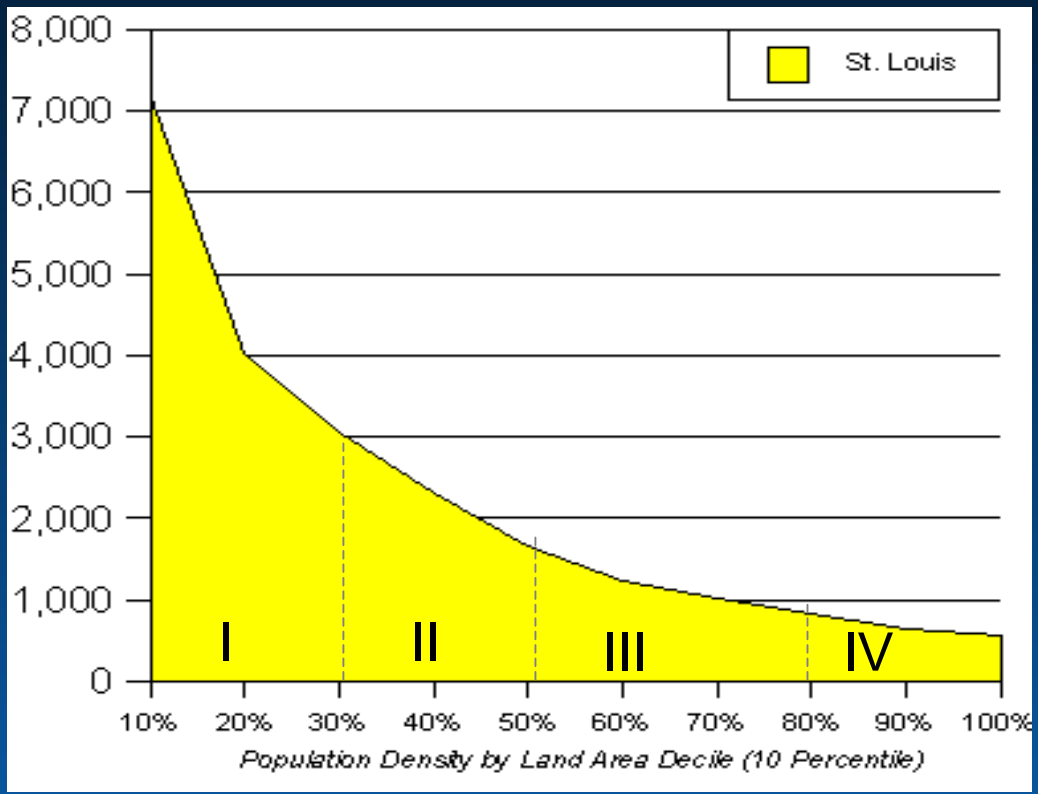
Skill Set - Studies

Delivery Component Model and Delivery Cost Analysis:
Population Density => Household Vehicle Density => H_2 Demand



- Population density consistently peaks in 10-20% of urbanized area
- Shape of density function (rate of decline) reflects compactness vs. sprawl
- HH vehicle density rises from <0.5/capita in core to 1.16/capita in outer zones

Future

- Remainder of FY03:
  - Incorporate energy efficiency and environmental measures (Summer ‘04)
  - Website with spreadsheet tool, results, and detailed documentation (Summer ‘04)
  - Complete delivery component and scenario cost analysis (Fall ’04)
  - Complete remaining cases (Fall ‘04)
  - Peer-reviewed paper (Fall ‘04)
  - Plan for next phase of H2A
    - Transition analysis
    - End-point analysis

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Analysis Issues

- Coordination
- Cooperation
- Interaction
- Peer-review